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Original Article

Efficiency Analysis of Capture Fisheries in the Northern and Southern Coastal Regions of Central Java, Indonesia

Hapsari Ayu Kusumawardhani[1*], Arisanti Ayu Wardhani[2]

[1]Economics Studies, Faculty of Economics and Business, Universitas Diponegoro, Semarang, Indonesia
[2]Study Program of Entrepreneurship, Faculty of Health Sciences and Technology, Socio-Humanities, Telogorejo University, Semarang, Indonesia
Email: [1)] hpsrayu@lecturer.undip.ac.id, [2)] arisanti@stikestelogorejo.ac.id

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Abstract

This study examines the fishery efficiency in the northern and southern coastal regions of Central Java by applying the Data Envelopment Analysis (DEA) approach. The efficiency measurement is based on three input variables (number of fishermen, boats, and fishing gear) and two output variables (total production value and quantity of fish produced). The analysis reveals that Tegal City is the most efficient region in Central Java's fisheries sector, followed by Rembang, Pati, and Batang. These regions demonstrate relatively optimal utilization of available fishing resources to generate high output. Tegal's efficiency can be attributed to its integrated fishing infrastructure, better market access, and effective fleet and labor management. In contrast, other regions showed lower efficiency due to underutilization of resources or operational constraints. The findings suggest the need for targeted policies to enhance technical efficiency in lagging areas, such as capacity-building programs, modernization of fishing gear, and improved value chain integration to support a more balanced and sustainable fisheries development across Central Java.

Keywords: Capture Fisheries, Central Java, Coastal Regions, Data Envelopment Analysis, Technical Efficiency.

1. Introduction

The wealth of natural resources strengthens the economy, contributing significantly to the Gross Regional Domestic Product (GRDP) and the community's welfare within a region (Oluwaseyi Musibau et al., 2022; Saleh et al., 2020). However, economies based on natural resources, such as agriculture and fisheries, are influenced by various factors, including inputs, outputs, and policy aspects that affect the stability of these sectors (Heryawan et al., 2016). Fisheries are one of the important sub-sectors in the agricultural sector, along with food crops, plantations, livestock, and forestry (Tanjung et al., 2021). Indonesia has an Exclusive Economic Zone (EEZ) of 200 nautical miles from its coastline, granting it the right to utilize the natural resources contained therein. With its high economic potential and value, this sub-sector plays an important role in providing livelihoods for the community, especially for fishermen and coastal communities (Bashir et al., 2019; Indrabudi et al., 2025). The fisheries sub-sector also plays an important role in encouraging equitable development among regions and improving the standard of living for people in various parts of the Indonesian archipelago (Adnan et al., 2021; Ahmad & Farooq, 2010; Anríquez & Stamoulis, 2007; Ismi & Budi, 2020). Furthermore, the fisheries sector plays a vital role in coastal economies, particularly in countries like Indonesia, where capture fisheries support the livelihoods of millions (Kaczan et al., 2023; McClennen, 2012).

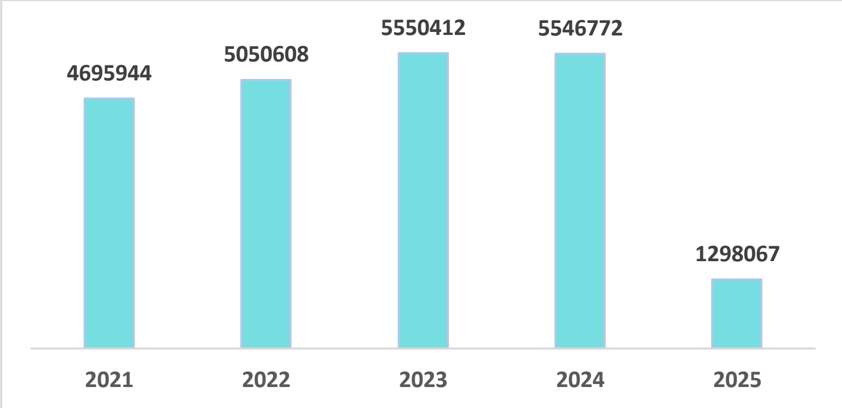

Figure 1. Gross Domestic Product at Current Market Prices (in Billions of Rupiah)
Source: Processed data from the Ministry of Marine Affairs and Fisheries (2025)

Based on data from the Ministry of Marine Affairs and Fisheries, Central Java Province is a key contributor to fisheries production. For the past five years (2021–2025), Central Java has ranked among the top five provinces with the most significant capture fishery production in Indonesia. As a province with extensive coastlines on its northern and southern territories, Central Java plays a strategic role in supporting the national capture fisheries sector (Ujianti et al., 2024). The capture fishery activities in the North Coast and South Coast regions establish Central Java as an economic center for this industry, which warrants attention in analyzing efficiency and marine sector policies.

The North Coast region of Java is well-established as a thriving hub for capture fisheries, supported by superior port infrastructure, vessel fleets, and market access compared to other coastal areas (Ningsih et al., 2022). In addition to its northern coastline, which has long been a center for fishery activities, Central Java Province also possesses a southern coastal region with high potential in the capture fisheries sector. These two coastal regions establish Central Java as a strategic economic center for capture fisheries in Indonesia (Warren & Steenbergen, 2021). Capture fisheries rely on productive inputs such as fishing labor and vessels. In 2023, Central Java had 227,900 fishers, complemented by 53,983 vessels operating in its marine waters (Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia, 2025). While the sector depends on physical capital, labor, and human resources, increasing these inputs does not always yield a proportional output. Therefore, efficiency must be measured to ensure that inputs are utilized optimally. Efficiency analysis helps identify regional disparities and provides empirical grounds for policy interventions aimed at improving performance and preserving marine ecosystems.

Although capture fisheries in the northern and southern coastal regions of Central Java both play a crucial role in supporting the regional and national economies, studies on fishery efficiency in these areas remain dominated by partial analyses. These studies tend to focus on a single region from a technical, economic, or social perspective (Ningsih et al., 2022; Ujianti et al., 2024). This study incorporates a comparative approach by simultaneously analyzing capture fisheries efficiency in the northern and southern coastal areas of Central Java, using the Data Envelopment Analysis (DEA) method. This approach allows for evaluation of technical performance across regions based on measurable input and output variables, providing a more comprehensive picture than previous, fragmented studies. Research on the north coast generally highlights declining productivity due to habitat degradation and ecological pressure. In contrast, studies on the south coast more frequently discuss the influence of oceanographic factors on catch yields without directly linking them to economic and social efficiency (Warren & Steenbergen, 2021). Furthermore, the limited availability of economic and supply chain efficiency data for the southern region, coupled with the absence of comparative studies based on the primary commodities of each area, reinforces the need for research that integrates the analysis of technical, economic, and social efficiency between the north and south coasts of Java (Kaczan et al., 2023). This study research novelty lies in the comparative analysis of capture fisheries efficiency in the northern and southern coastal areas of Central Java with the Data Envelopment Analysis (DEA) approach. This approach provides a previously rarely used empirical basis for formulating more optimal and sustainable capture fisheries management policies in both strategic areas. Thus, this comparative research is necessary to provide an empirical basis for formulating more optimal and sustainable capture fishery management policies for both strategic regions. Therefore, this study aims to analyze the fishery efficiency on the northern and southern coasts of Central Java.

2. Literature Review

2.1. Efficiency Theory in Capture Fisheries

Efficiency in capture fisheries is a concept that assesses the extent to which a fisheries business unit, such as a ship or region, can maximize the output (fish catch) from a certain number of inputs (Number of fishermen, boats, fishing gear) without wasting resources. Efficiency is achieved when a business unit produces the maximum output from a combination of available inputs or uses the minimum input to achieve a certain output level. In practice, technical efficiency is often measured using the Data Envelopment Analysis (DEA) or Stochastic Frontier Analysis (SFA) method, which compares actual performance with potential performance based on the same input (Jueseah et al., 2021; Phuong et al., 2023; Zhaoqun et al., 2018).

Various factors, such as the skipper's experience, the vessel's age and size, the number of crews, the fishing gear's technology, and the operation cost, greatly influence the efficiency level in capture fisheries. A study in Haizhou Bay, China, found that the technical efficiency of fishing vessels is still low, characterized by resource waste and suboptimal catch potential (Zhaoqun et al., 2018). Factors such as the age of the ship, the length of the operating days at sea, and the annual cost have a significant effect on efficiency (Onyshchenko & Melnyk, 2022; Zhao et al., 2022; Zhaoqun et al., 2018). In addition, technical training, fleet modernization, and collaboration between business actors can significantly increase technical efficiency (Jueseah et al., 2021; Phuong et al., 2023).

High efficiency is essential to ensure the sustainability of fishery resources, increase fishermen's income, and support the economic growth of coastal areas. Therefore, measurement and analysis of technical efficiency are important in formulating data-based and sustainable fisheries management policies (Ji & Li, 2021; Zhaoqun et al., 2018).

3. Methods

Based on the theoretical study, this research uses two approaches: Data Envelopment Analysis (DEA). In principle, DEA calculates the efficiency score of the inputs and outputs used by weighting each input and output (Amirteimoori & Allahviranloo, 2024; Peres et al., 2025). The data are obtained from the Ministry of Maritime Affairs and Fisheries in 2025; however, the available data only cover up to 2023. The advantages of DEA include that it does not require certain assumptions about the function of inputs and outputs and does not require restrictions in the weighting of inputs and outputs (Heryawan et al., 2016). DEA analysis was conducted to analyze the efficiency of capture fisheries in Central Java Province on the northern and southern coasts of Java. In general, the DEA model for this study is as follows:

$\theta{*}= \theta$ subject to

$\sum_{j=1}^{n} \lambda_j \chi_j \ \leq \theta \chi_i$

$\sum_{j=1}^{n} \lambda_j \chi_j \ \geq \ y$

$\sum_{j=1}^{n} \lambda_j = 1$

$\lambda_j \geq 0$

Where θ is the efficiency score, j, x, and y are period, input, and output, respectively. The input variables are the number of fishers in the location of the study, the number of ships, and the number of fishing gear. The output variables are the number of fish produced and the fish production.

This research was conducted in Central Java Province, with units of the south coast and north coast areas (Brebes Regency, Tegal city, Tegal Regency, Pemalang Regency, Pekalongan City, Batang Regency, Kendal Regency, Semarang city, Demak Regency, Pati Regency, Jepara Regency, Rembang Regency, Cilacap Regency, Kebumen Regency, Purworejo Regency).

The efficiency score obtained is provided that if eff=1 then it is called efficient and constant return to scale, if eff<1, then it is called inefficient and decreasing return to scale, and eff>1then it is called inefficient and increasing return to scale. Furthermore, the list of inputs and outputs selected is described in Table 1.

Table 1. List of Inputs and Outputs Selected

No	Input	No	Output
1	Number of fishers (person)	1	Marine Capture Fisheries Production - Marine Capture Commodities (kg)
2	Number of the ships (unit)	2	Value of Marine Capture Fisheries Production - Marine Capture Commodities (rupiah)
3	number of fishing gear (unit)		

Source: Ministry of Maritime Affairs and Fisheries (2025)

4. Results and Discussion

4.1. Descriptive Statistic

In this case, the observed data set's data characteristics are based on descriptive statistical calculations. The characteristics of the variables are reviewed based on the Input and Output variables, which include the indicator of the Number of Fishermen (Setiarso et al., 2014), the Number of Ships, the number of Fishing Equipment, Production (Kg), and Production Value (Rupiah).

The average number of fishermen in districts/cities in the Central Java region is around 14 thousand people, but the median value is only 11,105. This shows an uneven distribution, where some areas with many fishermen such as Cilacap pull the average upwards. In the variable number of ships, the average was recorded at 3,370 units, while the median was only 1,936 units. This indicates that most regions have a relatively small number of ships, but there are two areas with many ships, namely Demak (18,027 units) and Cilacap (10,236 units). This condition illustrates the inequality of fisheries facilities between regions.

Table 2. Descriptive Statistics

Sample	Indicator	Average	Median	Minimum	Maximum
Input	Fishers	14476	11105	345	37803
	Number of ships	3370	1936	158	18027
	Number of fishing gear	2697	2725	350	5200
Output	Production (Kg)	22.997.674	9.038.320	67.884	79.846.704
	Production value (Rupiah)	4,40625E+11	1,76041E+11	29599962000	2,49709E+12

Table 2 shows the results of the average, median, minimum, maximum, and standard deviation values for each variable. The findings show that the fishing gear variable relatively balanced average and median values, reflecting a fairly even distribution of fishing gear across regions. For the production variable, the average value of 22.99 million kg is significantly higher than the median of 9.04 million kg, indicating the presence of regions with very high catches, likely due to differences in the number of fishermen, the number and type of fishing gear, and geographic factors. As for the production value variable, the difference between the average and median is quite striking, indicating that only a few regions achieve very high economic value from fisheries. For example, a region like Pemalang records a large production value despite not having as many fishermen or vessels as other regions.

Based on the results of the descriptive analysis, it is known that the number of fishermen in the study area shows quite significant variation, with the lowest number being 345 people in Purworejo Regency and the highest being 37,803 people in Cilacap Regency. The number of vessels also shows a similar pattern, with a minimum value of 158 units in Purworejo and a maximum of 18,207 units in Demak Regency. Meanwhile, the smallest fishing gear was recorded in Purworejo at 350 units, and the highest amount was recorded in Cilacap at 5,200 units. For the production variable, the lowest value was found in Purworejo at 67.88 tons, while the highest production was recorded in Rembang Regency at 79,846.70 tons. The production value is fairly wide, from IDR 2.96 billion in Purworejo to IDR 2.50 trillion in Tegal City.

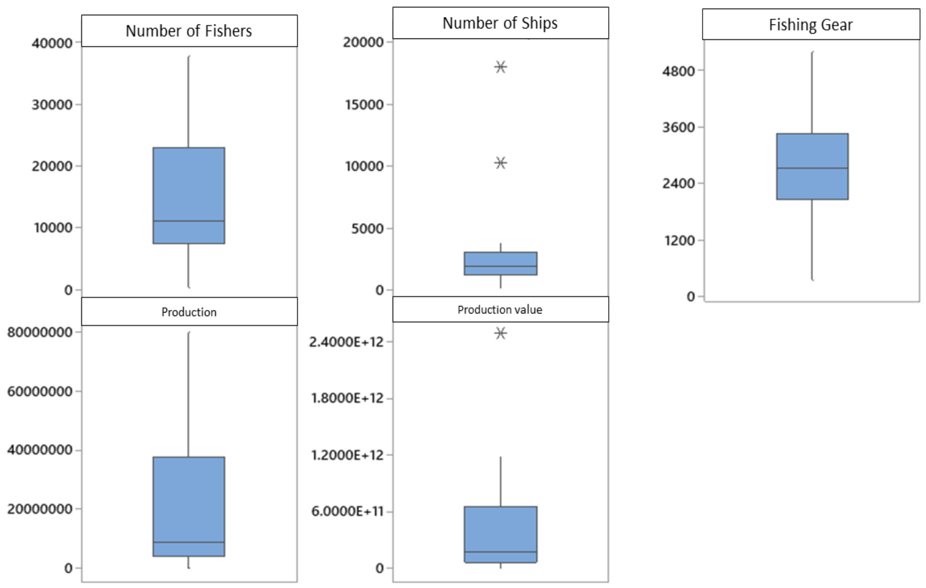

Figure 2. Boxplot Graph of Each Variable

The boxplot in Figure 2 shows the distribution of data and the presence of outliers for each input and output variable. The graph shows that the Fishing Gear and Number of Fishermen variables tend to be more evenly distributed. The number of ships and Production Value variables have outliers marked with an asterisk on the graph. This indicates clear regional disparities in the number of ships and Production Value variables. Outliers are important to consider when making policy decisions; don't just look at the average, as some regions are far more dominant and can obscure the conditions of other regions.

Table 3. Pearson Correlation Value between Input and Output

Input & Output	Number of Fishers	Number of Ships	Fishing Gear	Production	Production Value
Number of Fishers	1				
Number of Ships	0,348	1			
Fishing Gear	0,658	0,324	1		
Production	0,863	0,030	0,441	1	
Production Value	0,661	0,011	0,240	0,789	1

4.2. Correlation Between Input and Output

The statistical method used to measure linear relationships between variables is Pearson correlation. A positive correlation value indicates a positive and unidirectional relationship, while a negative correlation value indicates an inverse relationship. The general benchmark for Pearson correlation strength is as follows: The Pearson correlation calculation is based on data with the variables Number of Fishermen, Number of Vessels, Fishing Gear, Production, and Production Value.

Table 4. Pearson Correlation Value between Input & Output

Input & Output	Number of Fishers	Number of Ships	Fishing Gear	Production	Production Value
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Fishing Gear	0,658	0,324	1		
Production	0,863	0,030	0,441	1	
Production Value	0,661	0,011	0,240	0,789	1

Based on Table 4, the results show that, overall, the correlation values for each variable are presented. For example, the Pearson correlation coefficient between the Production Variable (Kg) and the Number of Fishermen is 0.863. This indicates a strong positive linear relationship, meaning that regions with more fishermen tend to produce more fish. This finding is logical because fishermen are the main workforce in fisheries production.

4.3. Fisheries Efficiency

The efficiency values for each Decision-Making Unit (DMU) for 16 Regencies/Cities in Central Java Province are as follows.

Table 5. Efficiency Value of Decision-Making Units (DMUs) of Each Regency/City in Central Java

DMU Name	Efficiency
Brebes Regency	0,13491
Tegal City	1,00000
Tegal Regency	0,10803
Pemalang Regency	0,84125
Pekalongan Regency	0,81845
Pekalongan City	0,45945
Batang Regency	0,90835
Kendal Regency	0,17200
Semarang City	0,19153
Demak Regency	0,18471
Pati Regency	0,96809
Jepara Regency	0,36279
Rembang Regency	0,98757
Cilacap Regency	0,42269
Kebumen Regency	0,33880
Purworejo Regency	0,08875

Source: Primary data processed, 2025

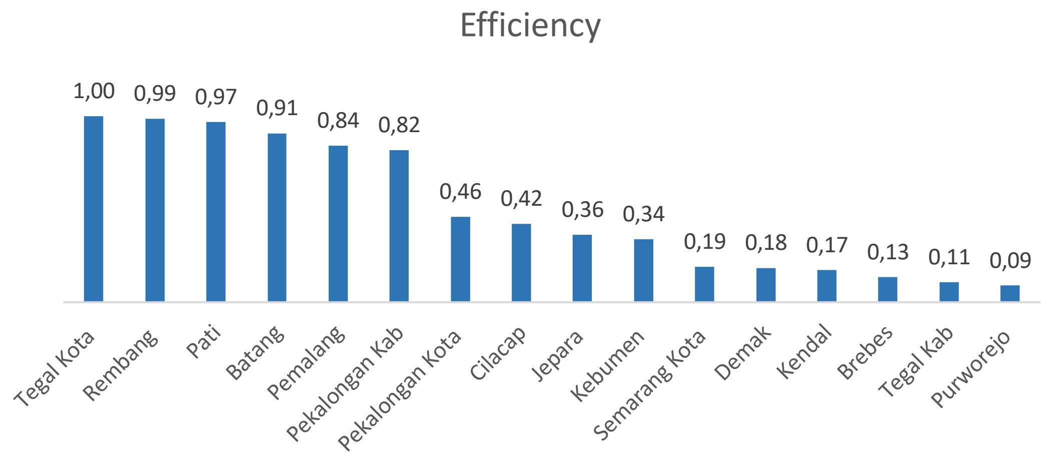

Figure 3. Visualization of Bar Chart of Decision-Making Units (DMUs) Efficiency Values for Each Regency/City (Highest to Lowest)

Based on Table 5 and Figure 3, it is evident that among the regencies/cities in Central Java Province, Tegal City demonstrates the highest efficiency, with an efficiency score of 1. This means that Tegal City is the most efficient in utilizing inputs (fishermen, boats, and fishing gear) to achieve the highest production and production value relative to other units.

All other Decision-making Units (DMUs) including the other regencies/cities can use Tegal City as a benchmark, as its performance remains below that of Tegal City. They can also learn from the input–output structure implemented by Tegal City. Rembang shows excellent efficiency performance, with a score reaching 0.99. Several other regions, such as Pati, Batang, Pemalang, and Pekalongan Regency, are also considered quite efficient, with efficiency scores ranging from 0.80 to 0.98. On the other hand, ten regions exhibit relatively low efficiency levels, specifically below 0.50. These regions include Pekalongan City, Cilacap, Jepara, Kebumen, Semarang City, Demak, Kendal, Brebes, Tegal Regency, and Purworejo. This condition indicates that these regions still need to improve efficiency in managing their capture fisheries sector by optimizing resources or enhancing their production systems.

4.4. Comparison of DEA Results with Inputs

Table 6. Comparison Values of Efficiency and Average Input

DMU Name	Efficiency	Average Input
Tegal City	1,00	6171
Rembang Regency	0,99	9961
Pati Regency	0,97	3647
Batang Regency	0,91	5234
Pemalang Regency	0,84	1810
Pekalongan Regency	0,82	3980
Pekalongan City	0,46	4925
Cilacap Regency	0,42	4480
Jepara Regency	0,36	2840
Kebumen Regency	0,34	11633
Semarang City	0,19	13191
Demak Regency	0,18	6255
Kendal Regency	0,17	12584
Brebes Regency	0,13	17746
Tegal Regency	0,11	4825
Purworejo Regency	0,09	284

Source: Primary data processed, 2025

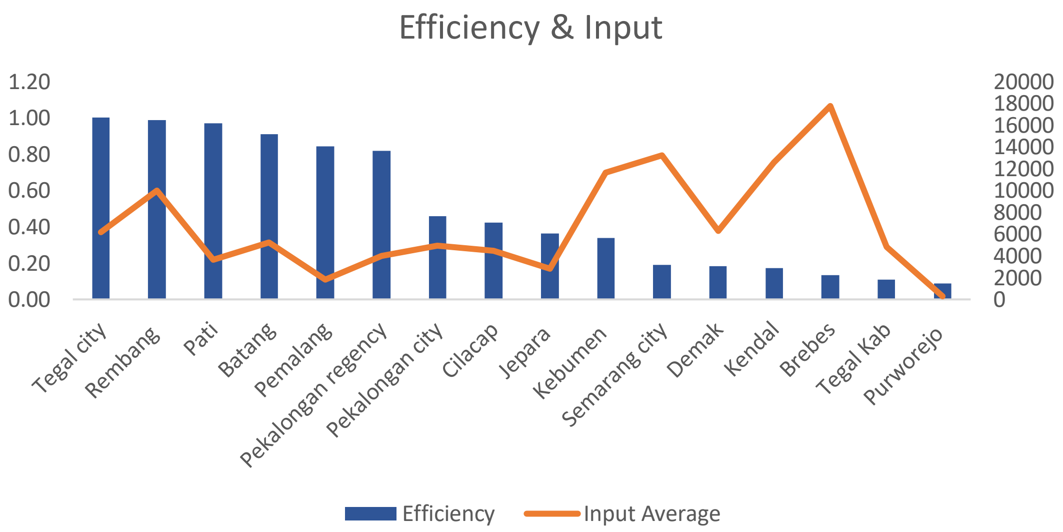

Figure 4. Comparison Graph of Efficiency and Average Input

Based on the DEA results in Table 6 and Figure 5, it can be seen that the efficiency of each region (DMU) is not always in line with the size of the inputs used. Tegal Kota was the only area to achieve perfect efficiency (1.00) with relatively moderate inputs, showing that optimal input management is much more important than just the number of inputs. On the other hand, some areas, such as Semarang City, Kendal, and Kebumen, have a high average input but low efficiency, indicating waste or ineffectiveness in resource utilization (Aboua, 2023; Adegbeye et al., 2020; Zhang & Luo, 2016). Meanwhile, areas such as Pati, Rembang, and Batang achieved high efficiency even though the input was not the largest, showing the potential for best practices that other regions could replicate. These findings confirm that efficiency depends on how well the input is used to produce output, rather than solely on the quantity of the input itself.

4.5. Comparison of DEA Results with Outputs

Table 7. Comparative Values of Efficiency and Average Input

DMU Name	Efficiency	Average Input
Tegal City	1,00	32739997803
Rembang	0,99	1248580029350
Pati	0,97	23486945850
Batang	0,91	124633050674
Pemalang	0,84	70612998363
Pekalongan Regency	0,82	7967781757
Pekalongan City	0,46	268354980801
Cilacap	0,42	40876695686
Jepara	0,36	38162329406
Kebumen	0,34	95507424622
Semarang City	0,19	590161128400
Demak	0,18	175724076183
Kendal	0,17	347774100893
Brebes	0,13	378578624732
Tegal Regency	0,11	80541346440
Purworejo	0,09	1480014942

Source: Primary data processed, 2025

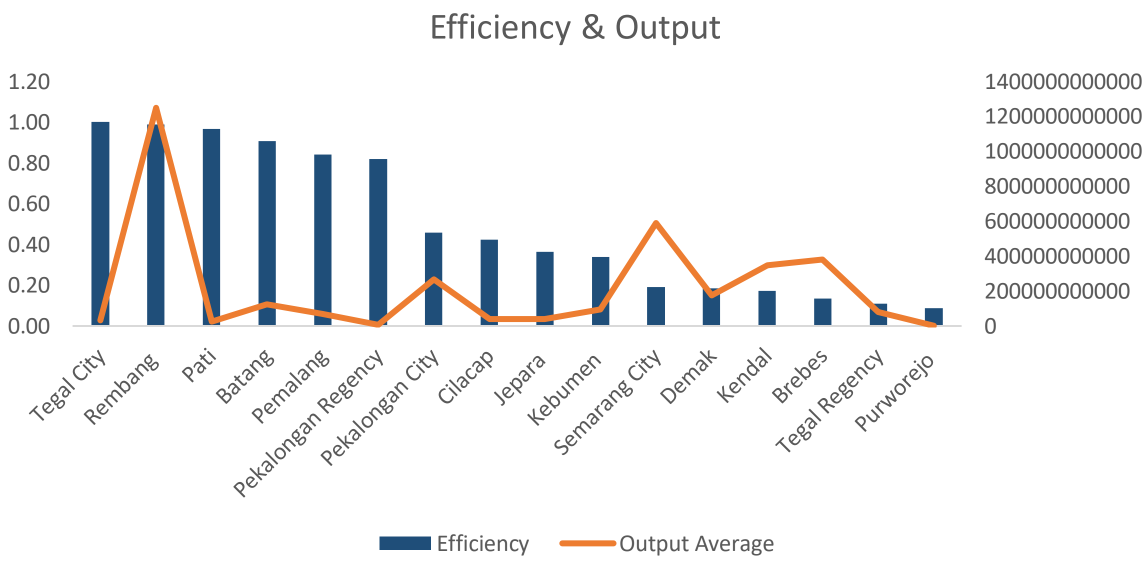

Figure 5. Comparison Graph of Efficiency and Average Output

Based on Table 7 and Figure 5, it can be seen that efficiency does not always correspond to the high output produced. Tegal Kota is the only DMU with perfect efficiency (1.00); large enough output, indicating optimal output utilization (Aparicio et al., 2021; Hermoso-Orzáez et al., 2020). Rembang, Pati, and Batang also demonstrate high efficiency, even though their outputs are not always the highest, indicating effective use of resources. Conversely, several regions such as Kendal, Brebes, and Tegal Regency have relatively large outputs but very low efficiency scores, suggesting that high output does not necessarily indicate efficiency if the inputs are significantly greater. This emphasizes that efficiency is not solely about the quantity of output, but rather the balance between the inputs utilized and the outputs produced.

4.6. Efficiency Optimalization

An efficiency value was obtained based on the results of the Data Envelopment Analysis (DEA) that has been carried out previously. In this case, those efficiency values can be optimized by reviewing the Slack results in the DEA. Slack in Data Envelopment Analysis (DEA) is an indicator that shows inefficiencies in the use of inputs or outputs in a Decision Making Unit (DMU) (Fatimah & Mahmudah, 2017; Parwoto et al., 2021) Slack describes how much input can be reduced or how much output can be increased without changing overall efficiency (Bourgeois, 1981; Sgourev & van Lent, 2017). In this case, for results, we will focus on each DMU (Regency & City in Central Java Province) as shown in Table 8.

Table 8. Slack's Value for Input & Output on Each DMU

No	DMU Name	Input Slacks			Output Slacks	
		Number of Fishers	Number of Ships	Fishing gear	Producti-on	Production Value
1	Brebes	0,00000	135,73475	347,53731	0,00000	102.840.775.139,03000
2	Tegal City	0,00000	0,00000	0,00000	0,00000	0,00000
3	Tegal Regency	0,00000	84,80238	240,15272	0,00000	24.639.189.986,41600
4	Pemalang	0,00000	1.936,21319	1.983,40764	0,00000	527.020.964.600,09800
5	Pekalongan Regency	0,00000	266,04405	2.160,47435	0,00000	27.309.980.282,52250
6	Pekalongan City	636,19559	0,00000	602,37770	0,00000	339.025.536.273,83200
7	Batang	0,00000	673,10261	1.045,17230	0,00000	441.212.583.202,81300
8	Kendal	0,00000	244,57159	192,66326	0,00000	74.869.723.361,82680
9	Semarang City	0,00000	307,60783	201,02672	0,00000	17.536.116.448,46920
10	Demak	0,00000	3176,39572	219,97994	0,00000	63.863.104.071,73940
11	Pati	2.345,47147	1.317,51224	0,00000	0,00000	1.714.967.535.733,80000
12	Jepara	0,00000	1123,53517	858,67758	0,00000	51.822.286.331,46200
13	Rembang	0,00000	833,44839	1.026,29777	0,00000	2.264.574.247.840,28000
14	Cilacap	0,00000	3.396,83540	620,50126	0,00000	787.620.076.285,43300
15	Kebumen	491,27342	641,02103	0,00000	0,00000	154.103.692.415,73900
16	Purworejo	0,00000	12,24053	28,03900	11960,52975	0,00000

Source: Primary data, processed 2025

Based on the results of Table 8, only Tegal Kota showed a zero slack value on all input and output variables, which means that Tegal Kota is the only truly efficient DMU that has utilized inputs optimally and produced maximum output. On the other hand, other DMUs still show technical inefficiencies, both in excess inputs and a lack of output.

Some areas, such as Demak, were recorded to have the highest input slack, namely 3,176.40 fishermen and 2,919.97 boats, showing great potential in reducing unproductive inputs. Unproductive inputs (Shero et al., 2022). Cilacap also has a high ship slack (3,396.84 units) and fishing gear slack of 620.50, indicating that the efficiency of fishing gear use needs to be improved. Meanwhile, Pati experienced an excess of input of 2,345.47 fishermen and 1,317.55 boats, even though the efficiency level was close to optimal.

On the output side, Brebes has a slack of production value of Rp102.8 trillion, meaning it can still increase the economic value of the catch without adding inputs. Semarang and Pekalongan Regency have a slack production value of IDR 52.7 trillion and IDR 27.3 trillion, respectively, showing economic output that has not been utilized to the maximum. In addition, Purworejo has a slack in the production of 11,960 tons, the only DMU that is slacking in the quantity of catches, showing that physical production in this area is still far from the maximum potential.

These findings show that most DMUs have significant room for improvement regarding input usage efficiency and output optimization. Data-driven policies such as resource reallocation, fisherman training, and fishing gear modernization can be strategies to improve regional fisheries efficiency.

5. Conclusion

The findings of this study reveal that only a few regions, such as Tegal City, align with the tagline “Maritime City.” Tegal’s success in efficiently utilizing its fishery resources, followed by Rembang, Pati, and Batang, has achieved optimal efficiency in utilizing fishing inputs to produce maximum output. At the same time, most cities and regencies still have considerable room for improvement. This inefficiency indicates suboptimal resource allocation and potential output losses in many coastal areas of Central Java. To address this gap, data-driven policies are essential. Suggestions for future research include adding variable outputs and eliminating undesirable outputs. Further research is recommended to compare efficiency across West Java, Central Java, and East Java. While Java has long been renowned for its robust fisheries,

Strategies such as reallocating resources according to local potential, providing technical training for fishers, and modernizing fishing equipment could significantly enhance the productivity and sustainability of regional fisheries. Furthermore, developing MSMEs and fisheries-based businesses, such as seafood processing, cold chain logistics, digital marketing of fishery products, and coastal ecotourism, is also key in extending economic benefits to the community. By supporting the growth of local entrepreneurs in this sector, technical efficiency can be improved while creating new jobs and strengthening the financial resilience of coastal communities. These efforts will improve technical efficiency and contribute to more equitable and resilient coastal development across the northern and southern coasts of Central Java.

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